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Environmental assessment of allergenic risk provoked by airborne grass pollen through forecast model in a Mediterranean region

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ABSTRACT

Airborne grass pollen is the main cause of allergenic diseases in many parts of the world although its frequency differs regionally. This risk could be included in the context of urban air pollution and climate change as environmental hazard and factors provoking allergies. The main objective of this study is to construct a local statistical forecasting model that takes the peculiarities of the daily average grass airborne pollen concentrations from an urban area placed in a city in the SW of the Mediterranean region with data from 24 years. It takes into account the temporal distribution of meteorological parameters (rainfall, relative humidity, maximum, mean and minimum temperature) for assessing the trend in the main pollen season. The Shuffle Complex Evolution Metropolis Algorithm has been used as an optimization function the Root Mean Square Error to accomplish this objective. Aerobiological survey was carried out with grass pollen data in Badajoz (SW Spain) using a 7-day volumetric sampler. The grass main pollen season lasted on average 88 days (April 18th to July 14th). One equation composed of two terms describes the model proposed to forecast airborne pollen. This equation integrates the short-term influence of the grass pollen concentration of the previous 10 days, as well as the actual pollen values, which is weighted by fitting coefficients applied to the most representative meteorological variables. Results obtained sustain the advisability of the developed model. Despite of goodness adjustment of the results to the obtained model, further long term analysis are needed regarding to other Mediterranean cities for expanding the knowledge of the trends and comparing the forecast in the Mediterranean region.

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1. Introduction

According to the Eurostat database (2017), there are several interesting statistics for the European population, one of them is quality of life over urban population exposure to air pollution by particulate matter (PM) of 10 μm (PM_{10}) and 2,5 μm ($PM_{2,5}$). Assessment of air quality and the identification of the main airborne pollen sources over the cities due to the increase of inorganic (Andersson and Eggen, 2015) and organic pollution (Irga et al., 2015) is being studied. The component inorganic has being deeply analysed (Fugiel et al., 2017; You et al., 2017; Zhang et al., 2016), but the part organic has less legislative interest. Because of the recent migrations of people to cities (Schmidheiny and Suedekum, 2015), there is more pollution in cities being necessary to know the content of organic (fungal spores and pollen grains) (Srivastava et al., 2012) and inorganic aerosols as oxides (Montero-Lorenzo et al., 2013; Quesada-Rubio et al., 2011) or Particulate Matter 10-PM_{10} (Ambade, 2016). Recorded data have presented that airborne pollen in the urban air keep electric charge, being possible to soak up particulate matter (PM) particles with potential pollutant power. This charge may affect the transport of pollen, enable of being captured by the floral stigma and promoting the deposition and accumulation of particles, allowing the interaction with the matters released from the pollen grain (Bowker and

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Crenshaw, 2007; Majkowska-Wojciechowska et al., 2016). The natural hazard due to biological sources of grasses and their dispersion have been cited as a risk factor of allergy over urban environments (Fernández-Rodríguez et al., 2016b) and as a significant source of bioparticles (Majkowska-Wojciechowska et al., 2016). There has been recently interest in aerobiological air quality research (Nayar and Jothish, 2013) that could be related with a new concept, urban green infrastructure (Breuste et al., 2015). Nevertheless, few studies have considered the airborne pollen as natural hazard (Fernández-Rodríguez et al., 2016a).

IPCC reports (2014) have recorded a rise of the global average temperature during the last two centuries and this trend will continue in the following years. Due to Climate Change, new studies have highlighted alterations in land cover distribution in the Mediterranean region (IPCC, 2014). Land cover changes and plant phenological response have been attributed to the impact of human activity on plant distribution as *Poaceae* pollen (García-Mozo et al., 2016). The effects of feedback structure and climate on *Poaceae* annual airborne pollen fluctuations and the possible consequences of climate change have been studied in the South of Spain (García de León et al., 2015). Moreover, the impact of the grasses and the human food have been evaluated taking into account the life cycle assessment (O'Brien et al., 2016; Wiedemann et al., 2015) and the effect of the Climate Change (Paroissien et al., 2015).

Grasses (*Poaceae* family) are one of the most numerous angiosperms groups in the world, including around 10,000 species distributed in more than 700 genera (Wang et al., 2013), with over 420 of these species occurring in Europe (Galán et al., 1989). Grasses pollen is an anemophilous (wind pollinated) plant group (Bogawski et al., 2014) that produce large amounts of pollen (12,000 and 22 million pollen grains) per inflorescence (Aboulaich et al., 2009; Prieto-Baena et al., 2003). Grass pollen concentrations used to peak in the morning (07:00h-11:00 h), while the minimum concentrations were reached at night (22:00h-04:00 h) (Galan et al., 1991). Peternel et al. (2006a) have reported the peaks in the period from 10:00 h to 11:00 h, and Latałowa et al. (2005b) found peaks in the morning as well, between 09:00 h and 13:00 h. However, other authors (Grewling et al., 2016) have found significant concentrations during night, which could be relevant for sufferers and allergists (Grewling et al., 2016; Latałowa et al., 2005a; Peternel et al., 2006b). Daily average grass pollen concentration is related with the meteorological parameters (Aboulaich et al., 2013; Bogawski et al., 2014; Plaza et al., 2016), having an special importance in the pre-pollination stage (Aboulaich et al., 2013).

Globally, grasses are the most important cause of pollen allergy in Europe because of the great allergenicity of their pollens and their extensive plant distribution (Newson et al., 2014). Although they include several thousand species, their allergenic importance is centered on a small number capable of producing abundant and airborne pollen (Bush, 1989; Weber, 1981). The subfamily *Pooideae* includes most of the genera responsible for allergies to pollen and there is an important cross-reactivity between them. In contrast, the subfamilies *Chloridoidae* (*Cynodon*) and *Panicoideae* (*Sorghum* and *Paspalum*), important as allergens in the USA, have a low cross-reactivity with *Pooideae*. The allergens of the different species of grasses present great physicochemical similarities that explain the cross-reactivity between them. These similarities have allowed the classification of allergens into groups, so that the components of the same group have in common certain molecular sequences regardless of the species of origin. Allergens in groups 1 and 5 are the most important because of the percentage of patients sensitized to them. While group 5 allergens are restricted to the *Pooideae* subfamily, group 1 allergens are present throughout the subfamilies of *Poaceae* (Davies, 2014; Newson et al., 2014).

Airborne grass pollen concentrations and their relation with the symptoms of allergic diseases in relation to the air pollution have been analysed (Erbas et al., 2012). Furthermore, temporal and spatial differences in grass pollen levels have been analysed (Fernández-Rodríguez et al., 2015a; Galán et al., 1995; García-Mozo et al., 2009; Rodríguez et al., 2014; Smith et al., 2009). In urban areas, it has been estimated the potential risk of allergy due to *Poaceae* pollen (Moreno-Sarmiento et al., 2015; Peel et al., 2014a; Rojo et al., 2016; Vesterberg, 2001) and the location of zones free of high airborne concentrations of *Poaceae* pollen through the production of forecasting models (Camacho et al., 2016). Recently, the pollen forecasting have been widely analysed by several tools; classic statistical based on daily values of airborne grass pollen and the Season Pollen Index (SPI) (Fernández-Rodríguez et al., 2015a; Kasprzyk and Walanus, 2010; Piotrowska, 2012; Puc and Wolski, 2013; Ugolotti et al., 2015a), 10-day mean concentrations (Makra et al., 2011), trends in airborne related to Climate Change (Bogawski et al., 2014; Damialis et al., 2007; García-Mozo et al., 2010; Jato et al., 2009; Tormo-Molina et al., 2010), multiple regression (Brighetti et al., 2014; de Weger et al., 2014; Myszkowska, 2014), seasonal-trend decomposition procedure based on LOcally wEighted Scatterplot Smoothing (LOESS) smoothing (STL) (Rojo et al., 2017), numerical models as SILAM (Sofiev et al., 2013), dispersions based on operational weather forecasts such as HYSPLIT (Van De Water et al., 2003) or COSMO-ART (Vogel et al., 2008) and artificial neural networks (Astray et al., 2016; Aznarte M et al., 2007; Iglesias-Otero et al., 2015).

The modelization of airborne pollen concentration has been developed in MATLAB, to evaluate the accuracy among observed and predicted average values. In the field of aerobiology, this multiparadigm numerical computing environment has been applied in several studies as the pollen data (Gong et al., 2015), the relationship between meteorological variables and the airborne pollen trends from ornamental plants as *Cupressaceae* (Silva-Palacios et al., 2016). But also in spontaneous and cultivated herbaceous (Fernández-Rodríguez et al., 2016a), wild origin as oaks and cork oaks (Fernández-Rodríguez et al., 2016c) and rural sources as olive trees (Fernández-Rodríguez et al., 2016d).

The goals of this study are to construct a local statistical forecasting model that takes the peculiarities of the daily average grass airborne pollen concentrations for 24 years of continuous recording. Also to assess the trend in the main pollen season, and to analyze trends in aerobiological data and to relate with meteorological trends (rainfall, relative humidity, maximum, mean and minimum temperature) from an urban area in the SW of the Mediterranean region. The Shuffle Complex Evolution Metropolis Algorithm has been used as an optimization function the Root Mean Square Error to accomplish these objectives.

2. Materials and methods

2.1. Sampling site

The current survey was taken in Badajoz, a city of Extremadura region (SW Spain) with grass pollen data from 24 years (1993–2016). Badajoz is a border town with Portugal, being the most populated city in this part of the Iberian Peninsula. The urban area (Fig. 1) extends about 8 km E-W and 6 km N-S and the surface occupied is 18 km^2 with the Guadiana river dividing the city from NE to SW. River banks and natural vegetation (including areas occupied by grasses) have been recently modified with a new urban public garden in the right part of the river of 27,000 square meters. According to Fig. 1, land is covered by irrigated crops at NE and SW (cornfields, fruit trees crops, rice crops and other horticulture cultivations), dryed crops and pastures appear at S, N and NW (weat

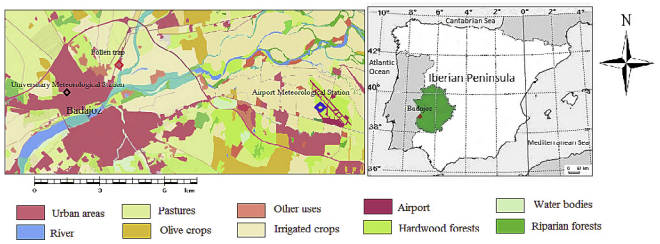


Fig. 1. Location of pollen trap, meteorological stations and land cover.

and oats), some small areas of holm oak and cork oak dehesa (hardwood forests) appears mainly in the S, sometimes shrublands appearing in the SW and SE. Also it is outstanding some olive crops located in the N of the city, and above all located in the NE. A 7-day volumetric sampler was used to record pollen (Hirst, 1952). Sampling point was located on an unimpeded terrace placed at 6 m above ground in a building belonging to Agricultural Engineering School, at University of Extremadura (38°53′45″N, 6°58′07″W). According to the previous published papers by Tormo-Molina et al. (2013) and Maya-Manzano et al. (2017a) the adhesive Petrolatum White (CAS number 8009-03-8) to capture airborne grass pollen was used. Standardised data procedures were followed as indicated by the Spanish Aerobiology Network (REA) (Galán et al., 2007). The grass main pollen season (MPS) was estimated using the 5–95% range (Nilsson and Persson, 1981) of the grass data. According to this criteria, the pollen season starts on the date when the sum of pollen grains from the beginning of the year reaches or exceeds 5% of the total annual pollen concentration, and ends when the 95% of this total is reached or exceeded. Grass pollen season features have been recently defined by parameters as day start, day end, day maximum, number of days, daily average count and Season Pollen Index (SPI) (Brighetti et al., 2014; Fernández-Rodríguez et al., 2016a; Ugolotti et al., 2015b). Fig. 1 includes an adaptation of the map of Badajoz from SIOSE ("Sistema de Información sobre Ocupación del Suelo de España") with the main land covers located around the pollen trap (IGN, 2016).

2.2. Climatic and meteorological data

Badajoz is characterised by a Mediterranean climate, with an influence of continentally. For the period 1981–2010 (AEMET, 2016), the maximum temperatures were recorded in the summer months, usually in July and August, with the mean temperature of 17.1 °C. Annual values of rainfall were 447 mm, with maximum rainfall in autumn and winter. The mean relative humidity registered was 64%. Wind speed was 9.5 km/h with SW (35.4%) and NW (26.4%) as predominant wind directions. Meteorological values were supplied by the AEMET from the airport meteorological station (38° 53′ N, 6° 49′ W) for the period 1993–2000 and from the university campus (38° 53′ N, 7° 0′ W) for the period 2001–2016 (Fig. 1). The mean temperature and the cumulative rainfall during all the period studied was compared with the log of the *Poaceae* concentrations, in grains/m^3. SPI of grasses and the selected meteorological variables (Mean, maximum and minimum temperature, rainfall, Relative humidity, cumulative rainfall for the previous ten days, mean temperature for the previous ten days and mean concentration for the previous ten days) was correlated by Spearman test.

2.3. Statistical analysis

For this study the prediction of grass pollen concentration was quantified using a mathematical model based on the meteorological variables. For the calibration of the non-linear parametric model proposed, we used the root-square error (RMSE) between observed and predicted values as optimization criterion. This purpose was achieved using the Shuffled Complex Evolution Metropolis algorithm (SCEM-UA), which has shown its accuracy in different predictive models from other science areas, such as hydrology, hydrodynamics or power systems (Efstratiadis and Koutsoyiannis, 2010; Li et al., 2017; Vrugt et al., 2003; Zi-Yand et al., 2015). The main purpose of this algorithm is the automatic selection of the set of parameters with the minimum value of the optimization criterion by evolving the initial proposal distribution of parameters to the best posterior target distribution, and thus, the combination of parameters that minimize the optimization criterion (RMSE in this case). Meteorological variables were; maximum (Tmax), mean (Tmean) and minimum temperature (Tmin), rainfall (R) and relative humidity (RH). Moreover, the variables of average temperature and cumulative rain in the last 10-days were also examined to know its degree of influence over pollen concentration. Additionally, the variables of grass pollen concentration of the previous day and the cumulative last 10-days were also considered. Meteorological and grass pollen data were gathered covering a 25-year period. The calibration period is composed by the first 17 years and the validation period for the last seven years, which correspond with the 70% and 30% of the length dataset, respectively.

3. Results

3.1. Trends

For the period studied (1993–2016), the value of SPI was 9,193, with a highest total peak of 20,272 in 2001 and a lowest total peak of 3004 in 2012. Daily average grass pollen concentration was 117 grains/m^3 for 1993–2016. The grass MPS lasted on average 88 days (April 18th to July 14th) and the day maximum was recorded on May 19th (Fig. 2). Fig. 3 shows a trend towards a shorter pollination period by delaying the start day (13 days) and advancing the last day (29 days) of the MPS. The day with maximum grass concentration is progressively closer to the day start, being the correlation between the day maximum and day start ($r = 0.242$, $p = 0.255$) higher than between the day maximum and the day end ($r = -0.017$, $p = 0.938$). Statistically significant correlation was

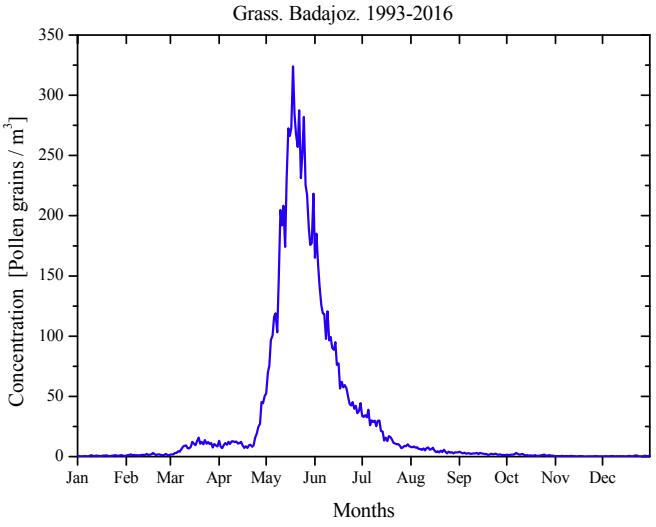


Fig. 2. Average daily concentration of grass pollen.

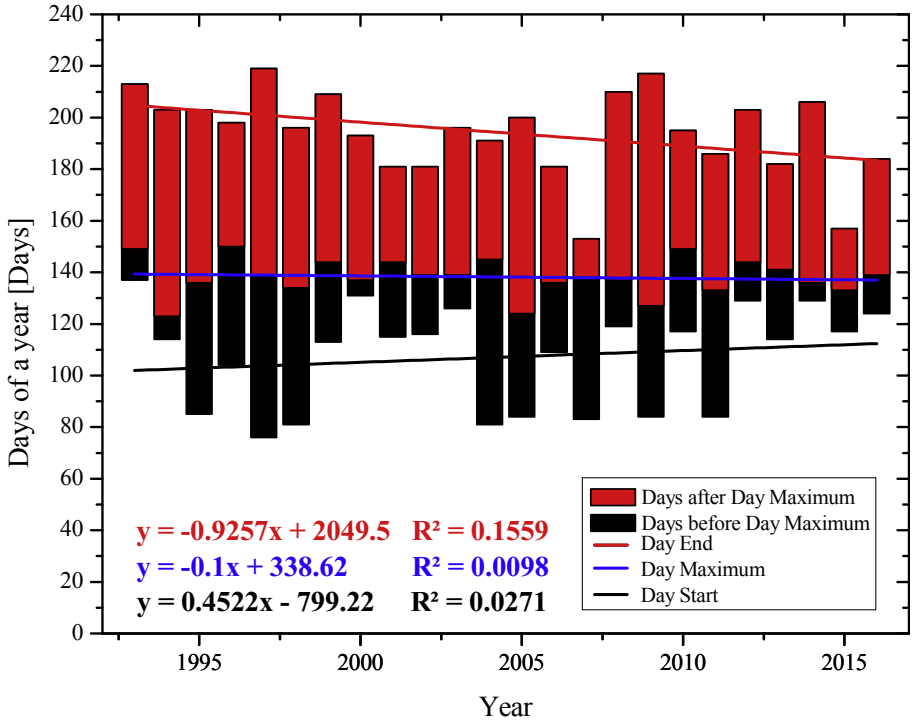

Days of a year [Days]
Year
y = -0.9257x + 2049.5 R² = 0.1559
y = -0.1x + 338.62 R² = 0.0098
y = 0.4522x - 799.22 R² = 0.0271
Days after Day Maximum
Days before Day Maximum
Day End
Day Maximum
Day Start

Fig. 3. Trends of grass pollen in the main pollen season.

found between number of days of grass MPS and daily average concentration ($r = -0.644^{**}$, $p = 0.001$), day start ($r = -0.737^{**}$, $p = 0.001$) and day end ($r = 0.595^{**}$, $p = 0.002$). Conversely, not statistically significant correlation was found between the SPI and the number of days of MPS ($r = -0.225$, $p = 0.290$). Note, significance at level 95% (*) and 99% (**). The dispersion of cumulative concentration in the MPS has been standardized in Fig. 4. As can be seen, the difference between the quantiles of 25% and 75% regarding to the average concentration is low, around 20 points in terms of percentage for the maximum differences. For the initial and final days of the MPS, the differences are even lower for both quantiles.

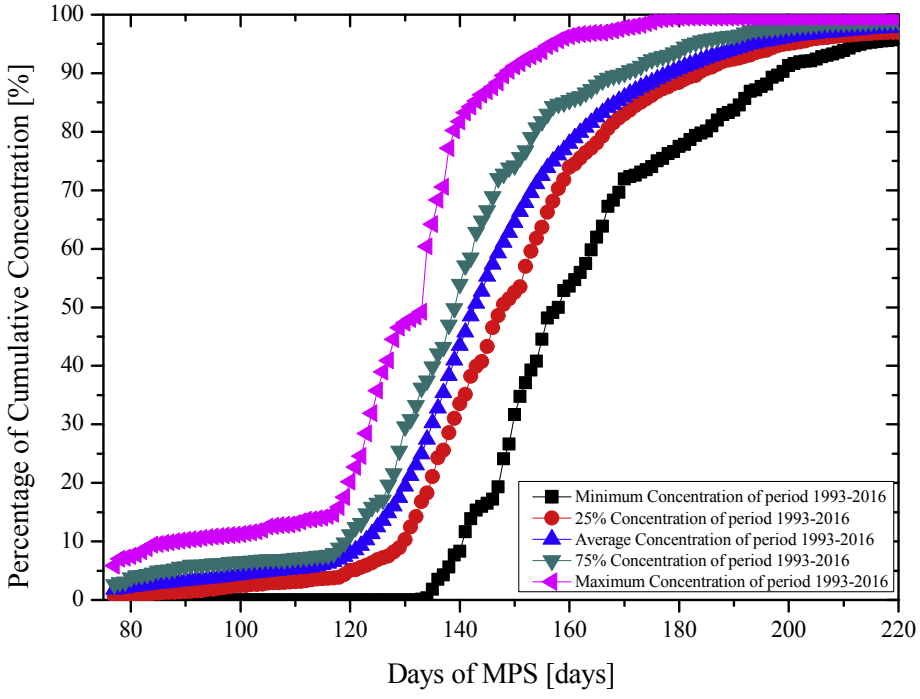

Percentage of Cumulative Concentration [%]
Days of MPS [days]
Minimum Concentration of period 1993-2016
25% Concentration of period 1993-2016
Average Concentration of period 1993-2016
75% Concentration of period 1993-2016
Maximum Concentration of period 1993-2016

Fig. 4. Characterization of percentage of cumulative concentration in the MPS for the period 1993–2016.

3.2. Relationship with meteorological variables

Average annual temperature in Badajoz has increased over the 24 years, revealing a clear and significant linear trend of 0.05 C°/year (Fig. 5a). Rainfall has also registered an increase of 3.08 mm/year (Fig. 5b). On the other hand, Fig. 5 a,b shows that the highest pollen concentration was reached with the range of main temperature 22-24 °C, showing and regular increasing with temperature from 6 °C forwards and with a relevant increase after 18 °C, then pollen abundance decrease quickly after 26 °C. In relation to accumulated rain, maximum presence of pollen appeared with a value of 175 mm; nevertheless, there is a marked heterogeneity in this relationship.

Fig. 6 shows the results obtained in the studied period. 24, 18 and 15 years have shown significance level for grass concentration, temperature mean and rainfall of 10 previous days, respectively. Secondly, temperature (maximum, mean and minimum) have registered 10, 13 and 10 years of statistically significant correlations, respectively. Relative humidity (12) and rainfall (7) are the least correlated meteorological parameters of the studied period.

3.3. Model

The grass pollen concentration (CP) is predicted by using the model defined by equation (1). This expression reflects two different time scale in the forecasting process: meanwhile the first term is related with the pollen concentration trend in the air of previous 10 days, the second term integrates the actual pollen concentration value with the most representative climatic variables multiplied by a fitting coefficient. To characterize the climatic behaviour of previous 10 days, the variables of average temperature and the cumulative rainfall of the previous 10 days are even included.

$$CP^{t+\Delta t} = a \cdot \frac{\sum_{i=t-10}^{i=t} CP^i}{10} + CP^t \left(b \cdot T^t_{max} + c \cdot T^t_{mean} + d \cdot T^t_{min} + e \cdot \frac{\sum_{i=t-10}^{i=t} T^i_{mean}}{10} + f \cdot R^t + g \cdot \sum_{i=t-10}^{i=t} R^i + h \cdot RH^t \right) \quad (1)$$

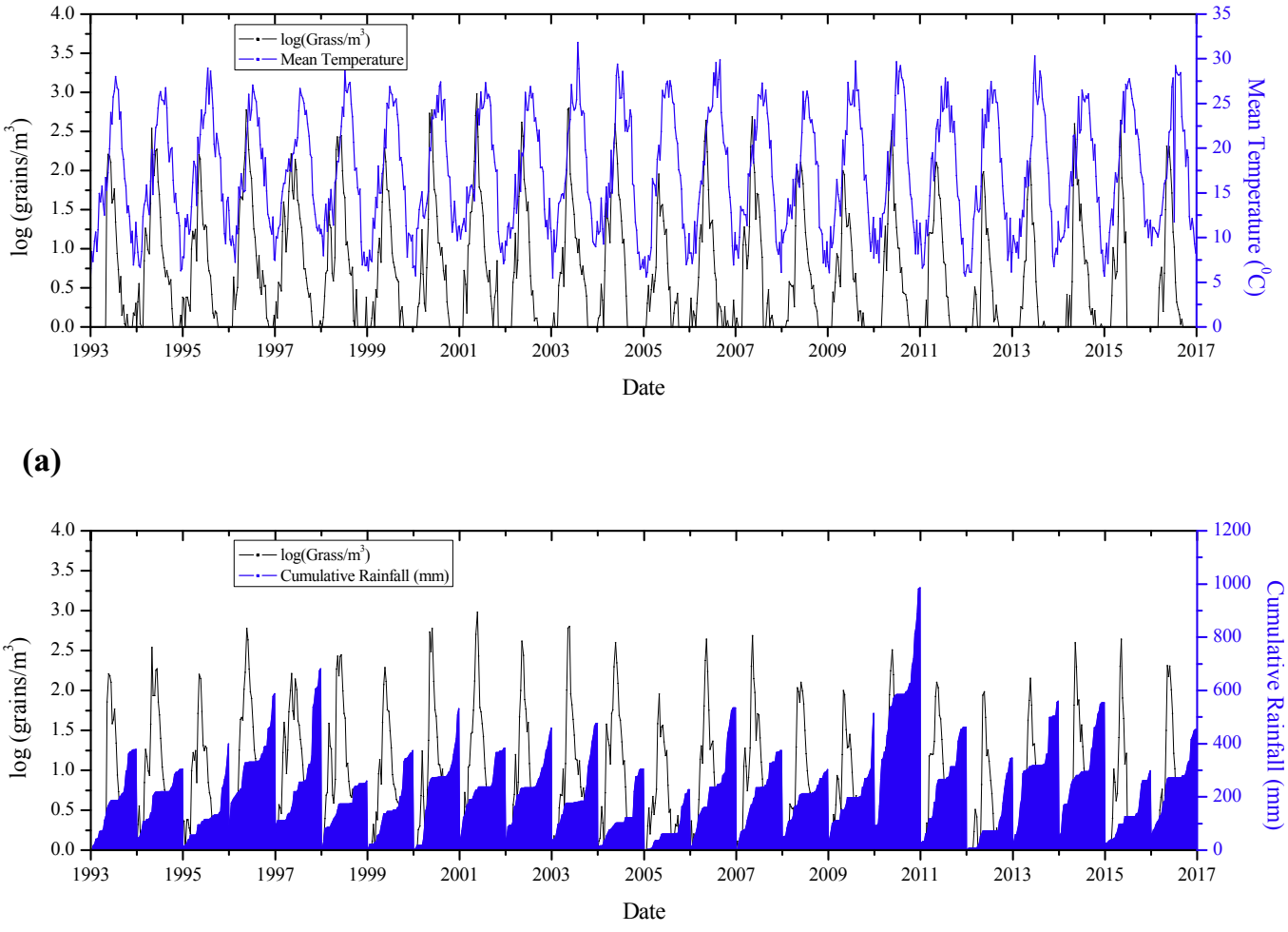


Fig. 5. Relation between grass pollen grains and temperature (a) and cumulative rainfall (b).

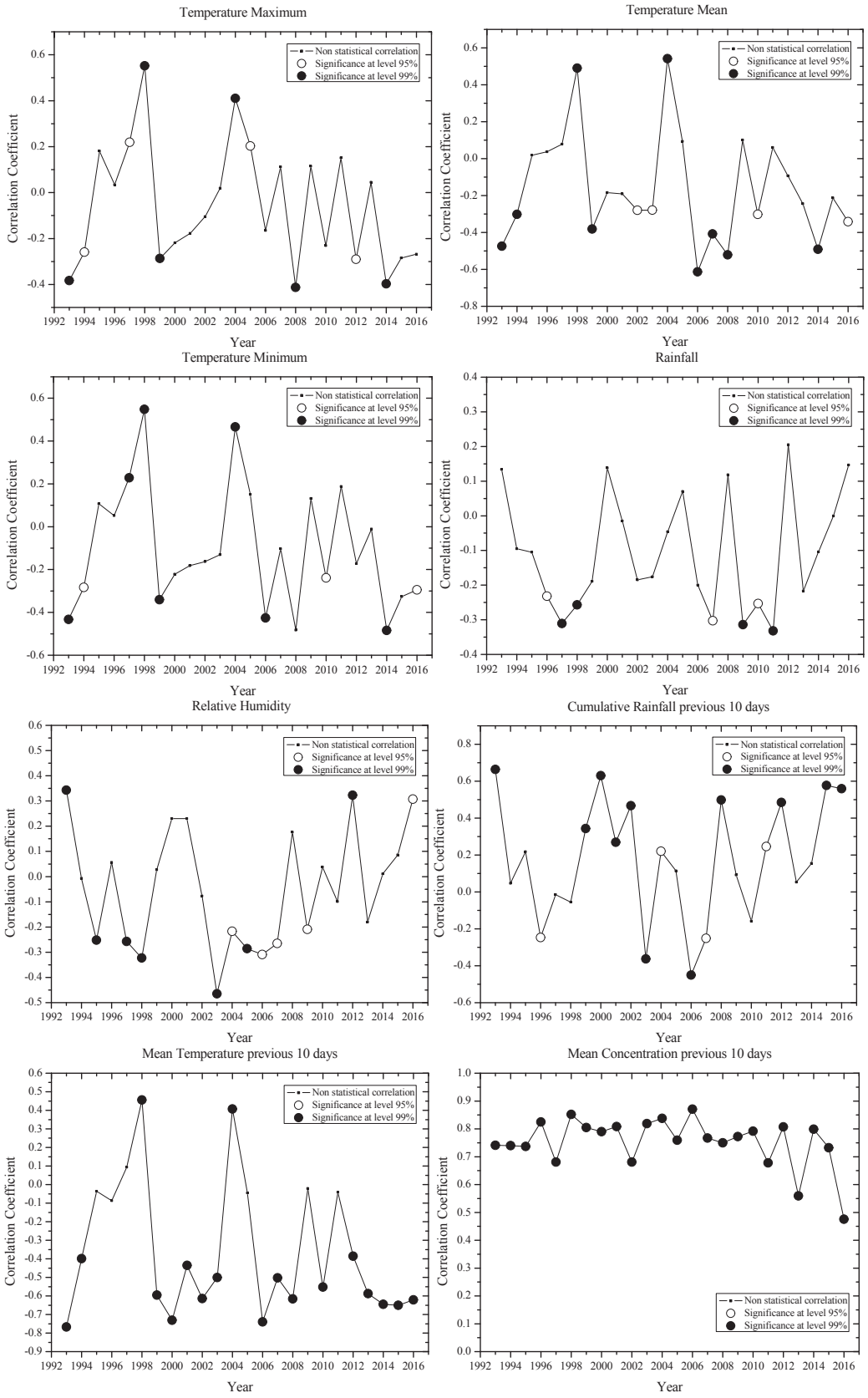


Fig. 6. Correlation coefficient between daily pollen concentrations during the SPI and meteorological parameter.

where a, b, c, d, e, f, g and h are the coefficients to be calibrated for our climatic time series and airborne pollen concentration and Δt is the time step considered for the forecasting process, which is fixed at one day. Furthermore, the suitability of the model is examined for longer time gaps equal to 5 and 10 days. For this purpose, Δt is fixed at 5 for a forecast time step of 5 days and at 10 for a forecast time step of 10 days.

Even though the relevance of all meteorological variables over airborne pollen concentration is not similar, it has been decided to keep them because of their range of variations are different among them as well as its mean value. The SCEM-UA algorithm helps to estimate the appropriate fitting parameters for this model.

Table 1 shows the values obtained for each parameter for the 24 years analyzed, and the value obtained for the criterion of the coefficient of determination (R^2). The model has been calibrated for the first 17 years and validated for the last seven years. We have no considered a cross-validation procedure due to the trends observed in the SPI. The average coefficients (R^2) in both periods are higher than 0.55 and for the different time prediction delay; for 1 day ($R^2 = 0.70$; 0.70), 5 days ($R^2 = 0.66$; 0.60) and 10 days ($R^2 = 0.63$; 0.57). For calibration, the optimization criterion (RMSE) has been established as a similar common value for the whole period (1993–2009). Once obtained the optimal dataset of parameters, we have simulated the pollen grass concentration for the validation period with this model parametrization obtained.

Fig. 7 shows the coefficient R^2 of each year to quantify the dispersion from to the average values for each period from the dataset. Additionally, we have evaluated the dispersion of the residual values obtained as difference between observed and simulated grass pollen concentration. Fig. 8 expose the probability density function for the calibration and validation period, in which the similar distribution is observed with an average value around 0, and a 95% confidence interval of average value between −8 and 10.

Regarding to the parametrization, in all cases with different time prediction delay, parameter “a” has shown the highest value, highlighting the importance of the trend of the previous days of pollen concentration. Maximum temperature indicated by parameter “b” has registered the highest value for the forecast to 10 days, nevertheless parameter “c” related with mean temperature for predicting 1 day was higher than 5 and 10 days. Parameter “d” linked to minimum temperature achieved the greatest value for 10 days as the maximum temperature. However, mean temperature of the 10 previous days (parameter “e”) has registered low values. Rainfall associated to parameter “f” has shown lower and negative values for 1 day and 5 days, meanwhile parameter ‘g’, which is linked to the mean rainfall of the 10 previous days, was positive. At last, the value of parameter ‘h’ (relative humidity) is second variable with more influence. Fig. 9 shows the posterior probability distribution function of all parameters (“a” to “h”) and R^2 for 1, 5 and 10 previous days. Red lines show the most accurate combination of parameters. As can be seen, the robustness of the set of parameters is verified due to the position of each red line is close to the value with higher probability and these outcomes are consistent for the three time predictions delay of 1, 5 and 10 days. Therefore, fluctuations around those parameters would not generate high differences in terms of R^2.

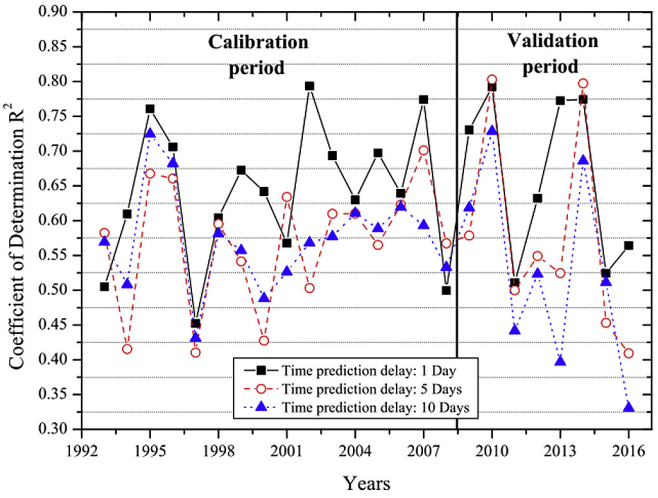


Fig. 7. Evolution of Coefficient of Determination R^2 along the calibration and validation period.

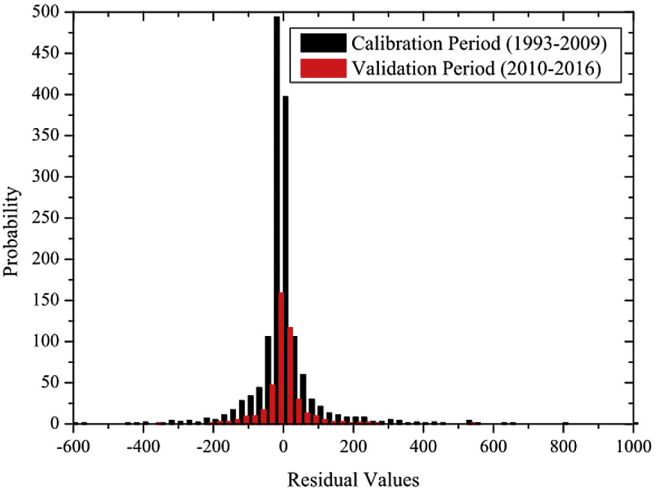


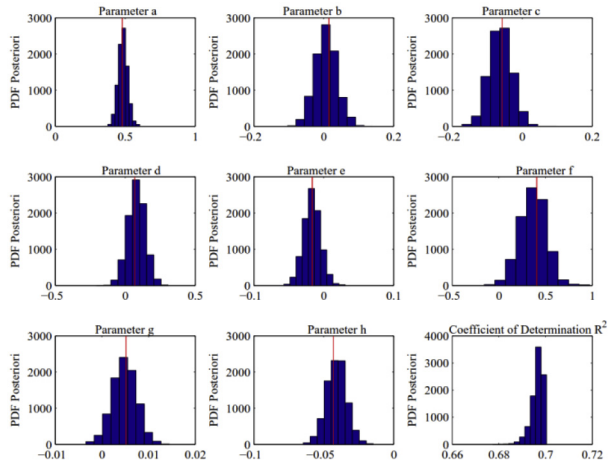
Fig. 8. Probability Denstion Function of Residual values for the calibration and validation period.

Table 1
Parameters of the model used to forecast grass pollen concentration (Day: previous day). $\overline{CCobs}$: Observed average grass pollen concentration $\overline{CCsim}$: Simulated average grass pollen concentration for each time prediction delay.

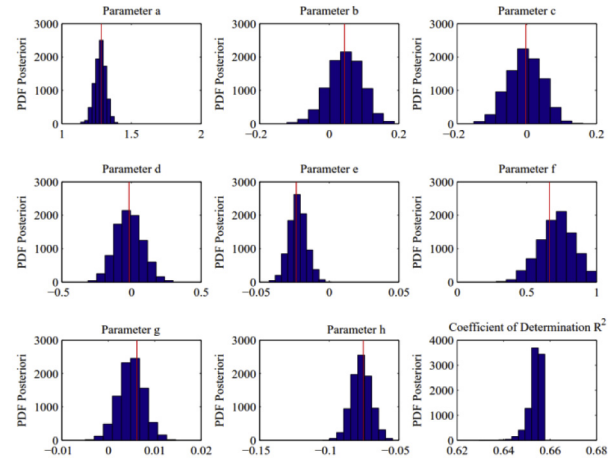
Parameters	Time prediction Delay		
	1-Day	5-Day	10-Day
a	0.479	1.284	1.118
b	0.015	0.045	0.059
c	0.068	−0.017	−0.085
d	−0.058	−0.003	0.047
e	−0.043	−0.076	−0.042
f	−0.016	−0.024	−0.029
g	0.005	0.006	0.007
h	0.406	0.662	0.231
Comparison criteria			
R^2	0.702	0.658	0.635
RMSE	96.924	103.592	107.502
$\overline{CCobs}$	103.627		
$\overline{CCsim}$	100.622	103.946	100.689

4. Discussion

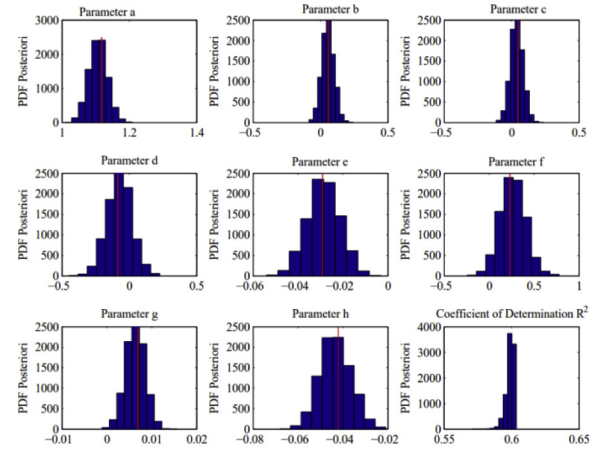
The results obtained in this study could be used to consider a risk factor the grasses and their grass pollen grains (Fernández-Rodríguez et al., 2016a, 2016b), within the idea of green infrastructure (Breuste et al., 2015), as an indicator to evaluate the environmental (Nayar and Jothish, 2013) in a city of the SW Mediterranean region. Recent papers carried out in Badajoz have reported that airborne pollen comes from median and long-distance



(a)



(b)



(c)

Fig. 9. Posteriori probability distribution function of parameters (a, b, c, d, e, f, g and h) and R2 of 1 previous day (a), 5 previous days (b), 10 previous days (c). Red line represents the more accurate combination of parameters. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

sources. Several studies in Extremadura have found that airborne organic particles, of pollen grains from olives (Fernández-Rodríguez et al., 2014) or oaks (Maya-Manzano et al., 2016), and from fungal spores as *Alternaria* (Fernández-Rodríguez et al., 2015b), comes not only from local but also regional sources when wind blew from West direction (Silva-Palacios et al., 2007). Grass pollen concentrations recorded in a site depends on environmental specific conditions (Muñoz-Rodríguez et al., 2010), being representative emission sources up to 100 km around the sampler (Domınguez et al., 1993; Fornaciari et al., 2000). Emission from nearby sources has been tested by Maya-Manzano et al. (2017b), who analysed the airborne pollen content in three cities of the same region and the land cover surrounding them by means of circular statistics. Certain pollen amounts are dispersed by long-distance transport (Fernández-Rodríguez et al., 2014; Maya-Manzano et al., 2016), but the importance of this transport depends on the size of the particle. Even in small pollen grains as olive pollen, long-distance transport explains several peak showing low and moderate intensity. Thus, the most important peaks with respect to pollen concentrations match with plants flowering on a local or regional scale (Rojo and Pérez-Badia, 2015). For this reason, the short-term pollen dispersal is often analyzed using 10–20 km distances from the pollen sources (Maya Manzano et al., 2017b; Rojo et al., 2015). Regarding grass pollen, new researches should analyze long-distance transport in order to improve the knowledge about the dispersal patterns of this pollen type.

Grass pollen is one of the most abundant pollen types in aerobiological studies carried out in Iberian Peninsula. In this study, the daily average values ranged from 26 to 303 grains/m^3 depending on the year analyzed. Higher concentrations were recorded by Fernández-Rodríguez et al. (2015a), with 166 grains/m^3 in Évora (Portugal) and 102 grains/m^3 in Worcester (UK) for the period (2005–2011). Average annual grass pollen peak was registered on the 19th of May. Similar date were recorded in the centre of Iberian Peninsula as in Guadalajara (Rojo et al., 2016), Toledo (García-Mozo et al., 2006) and Madrid (Sabariego et al., 2011), and in the South Spain, as in Málaga (Docampo et al., 2007). Rodríguez-Rajo et al. (2004) in Vigo (NW Spain) and Fernández-Rodríguez et al. (2015a) in Worcester (SW United Kingdom) recorded the maximum concentrations in July, because to the milder climate in NW Spain and SW United Kingdom.

According to (IPCC, 2014), the mean temperature has increased over 0.85 °C in the last 100 years. The meteorological trend registered in Badajoz over the last 24 years agrees with the tendencies recorded globally. Similar increase was found in Italy (Ghitarrini et al., 2017). Recent studies have highlighted the global warming due mainly to the increase of CH_4, CO_2 and N_2O in the atmosphere (Peacock et al., 2017). It may change the number of invasive species (Drake et al., 2017), the reproductive physiology and phenology plants (Jacques et al., 2015; Ziello et al., 2012), the production pollen (Zhang et al., 2014), the advance (Cola et al., 2016; Mulder et al., 2017), delay (Templ et al., 2016) or both (Blecharczyk et al., 2016) in the flowering time. Generally, the upward trend for temperatures in both winter and early spring have indicated that pollen seasons are starting earlier than in last century. Nevertheless these changes in this century are no longer consistent, being the data related to the seasonal pollen index SPI not conclusive (Malkiewicz et al., 2016).

Fig. 3 shows a narrowing of the MPS, with a delay of the day start and an advance of the day end, but the trends (day maximum, day start and day end) did not find statistically significant correlations. However, significant correlations were found between number of days of grass MPS and daily average concentration, day start and day end. Research conducted in Europe have shown a faster start of days per decade, due to temperature increase, for pollen season

from trees as hazel (Bissolli et al., 2005), birch (Frei and Gassner, 2008; Zhang et al., 2013), olive (Orlandi et al., 2017), or herbs as grasses (García-Mozo et al., 2010; Ugolotti et al., 2015a). However, this is not a common phenomenon, according to studies carried out in Central Europe (Slovakia) for *Corylus* pollen (Bissolli et al., 2005) or in SW Mediterranean region (SW Spain, Extremadura region) for pollen from trees; such as cypresses (Silva-Palacios et al., 2016), oaks and cork oaks (Fernández-Rodríguez et al., 2016c), olives (Fernández-Rodríguez et al., 2016d), or herbs (Fernández-Rodríguez et al., 2016a) have shown a delay of the pollen season. The decrease in airborne grass pollen in Badajoz (SW Mediterranean region) has been evidenced by the displayed negative slopes. Similar results have been found in Mediterranean areas such Portugal (Camacho et al., 2017) and Italy (Ghitarrini et al., 2017; Ugolotti et al., 2015a). However, opposite trends were shown in the North of Europe, UK (Smith and Emberlin, 2005) and in the South Spain (García-Mozo et al., 2010, 2016). In Spain and Italy SPI depends on the high variability between bioregions and seasons (Ghitarrini et al., 2017). García-Mozo et al. (2016) have revealed mixed trends depending on the taxa and reflecting fluctuations in land cover and/or climate. In this paper, e.g., *Poaceae* pollen concentrations increased, due largely to an expansion of heterogeneous agricultural areas, but other herbaceous pollen types such as *Amaranthaceae, Rumex, Plantago* and *Urticaceae* showed significant negative trends, which could be related to changes in urban planning strategies of construction. So, a future study combining circular statistics and GIS method with aerobiological data could be an useful tool for understanding pollen origin (Maya Manzano et al., 2017b). In our case, there are evidences to relate this trend with recent changes in the land uses and urban green management in Badajoz. In the last years, several roads, avenues, parks and buildings have been built around the reference pollen trap, replacing the natural green vegetation composed, in part, by grasses. Moreover, to reduce the urban allergenic load in Badajoz, it would be convenient to asses the influence of the urban infrastructure management (use of herbicides, quite grass cut or planting species with lower production of pollen) as it have been found in others cities (Ghitarrini et al., 2017; Hamón et al., 2017).

The relationship between the SPI and the number of days in the MPS did not find significant statistical correlations. Nevertheless, in Córdoba (S Spain), García-Mozo et al. (2016) have registered a rise of grass pollen concentration. In Poland, Piotrowska (2012) has shown a negative relation between SPI and season length, maximum concentration and ending day. In the current work, we have found statistical significant trends in MPS length and day start, day end and daily average concentration. On contrary, a lengthening mostly due to the advance of the pollen season start have been found by García-Mozo et al. (2010). Moreover, a trend of airborne pollen to be recorded earlier between onset and peak of pollination was found. These results agree with the previous phenological studies performanced in trees, which have shown a preview of the flowering for grass pollen (Myszkowska, 2014; Stach et al., 2008).

It is well known the influence of weather conditions have on grass pollen concentrations (Aboulaich et al., 2013; García-Mozo et al., 2009; García de León et al., 2015). The effect of temperature prior to flowering is essential for plant growth and achieve maturity, bringing the flowering time forward (Peel et al., 2014b). The positive relation between grass pollen and temperature (maximum, minimum and mean) and rainfall agrees with previous papers (García-Mozo et al., 2016; Muñoz-Rodríguez et al., 2010). Secondly, the pollen release depends on other meteorological parameters (rainfall and relative humidity influence) (Laaidi, 2001). This study did show a strong relationship between grass pollen and temperature mean and rainfall of 10-days-back. This fact could be explained due the relationship between the development of the herbaceous taxa (Poaceae) and the effect the temperature (Piotrowska, 2012) and rainfall cumulative (Matyasovszky et al., 2015). Moreover, it has been cited the influence of rainfall, humidity accumulations, sunlight hours and rain features in the pollen release during flowering period for forecasting long-term horizon (Aguilera et al., 2015). The wind was not considered due to the spot influence that has been demonstrated for ornamental species such as grasses in local environments (Rojo et al., 2015). The adverse effect found of the relative humidity and grass pollen is in line with other studies (Aboulaich et al., 2013; Moreno-Sarmiento et al., 2016; Simoleit et al., 2016).

There is a widely evidence of the existence of short term forecast due to the higher accuracy of the model proposed (Navares and Aznarte, 2017). Our approach model is in line the idea to consider more relevant the previous pollen daily observations and 10-day cumulative airborne concentrations developed by Navares and Aznarte (2017). The results of the parameter “a” confirm this fact. The biological reason is due to both features may to serve as indicators of the state of growth of the plant (Ribeiro et al., 2007). Furthermore, meteorological parameters have been considered in our study for forecasting the predictive value more accurately. Maximum and minimum temperature and rainfall have been used by Rojo et al. (2017) to forecast grass pollen for 1, 2 and 3 previous days with values in line the present study. Relative humidity has been the main meteorological variable related for forecasting daily pollen. Peel et al. (2014a) have explained the relation between the increase of relative humidity and the possible causative mechanism involving moisture mediated pollen grain buoyancy in urban environments. Secondly, daily average temperature and average temperature of the previous 10 days have been the meteorological variables with more influenced to forecast grass pollen concentration. Dahl et al. (2013) have highlighted a time lag reaction to the meteorological variables with herbs such as grasses with respect to elements of the arboreal stratum, even different response have been found for a condition meteorological as minimum temperature, positive for trees and negative for herbaceous plants in the Mediterranean region (Hadj Hamda et al., 2016). This phenomena has been argued because the trees are more resilient to increases in temperatures and relative humidity than herbaceous as grasses (Recio et al., 2010).

There is statistical evidence of the existence of relevant groups of variables when forecasting 1 day-ahead airborne pollen concentrations (Navares and Aznarte, 2017). This study have shown results (R^2 0.70), using the multiple regression. This is in line of accuracy to other studies for *Plantago* pollen with average R^2 of 0.66 using Artificial Neural Networks (ANN) (Iglesias-Otero et al., 2015), or for *Poaceae* pollen between 0.65 and 0.52 depends on the reduction of variables by random forests for regression in several cities of Madrid region (Navares and Aznarte, 2017) or the grass pollen between 0.58 (pre-peak) and 0.69 (post-peak) in Toledo (Rojo et al., 2017). Our forecast for 1 day ahead have recorded a value lower for *Olea* pollen, 0.77, (Fernández-Rodríguez et al., 2016d), but higher than cited for the other pollen types; *Cupressaceae* pollen, 0.30 (Silva-Palacios et al., 2016) and 0.46 (Sabariego et al., 2012), *Quercus* pollen 0.58 (Fernández-Rodríguez et al., 2016c), and *Betula* pollen, 0.44 (Ritenberga et al., 2016). More days have been forecasted for grass pollen, 7 days ahead, between 0.47 and 0.62 (Smith and Emberlin, 2005), 15 and 30 day ahead, 0.62 and 0.57 respectively (Fernández-Rodríguez et al., 2016a). Furthermore, for this analysis of the entire time period, the fit of the model was examined for a forecast horizon of 1, 5 and 10 days. The R^2 values obtained were 0.70, 0.66 and 0.63, respectively, which show a trend in decreasing order with accurate results in all cases. The combination of these results with the distribution of posterior

probability of parameters and the criterion of R^2 corroborates the suitability and the strength of the proposed model as an efficient tool to forecast airborne grass pollen up to 10 days. This forecast is obviously depending on the earliest availability of data, usually pollen data from commercially Hirst sopre traps delay 1–7 days (Galán et al., 2014). We consider that it would be better an automatic pollen monitoring that is improving for the next close future (Crouzy et al., 2016; Oteros et al., 2015).

5. Conclusions

The rise of air temperature in SW Spain, such as in many other areas of the Mediterranean region and evidenced in this study also, it is alleged that has produced changes of the characteristics of airborne grass pollen in the last years. This study considers the grass airbone pollen as a natural risk to consider into urban green infrastructure and may be used by allergists for improving the quality of life of patients. The model supplies a suitable level of confidence (R^2) to forecast grass airborne pollen concentration for 1 day (0.70), 5 days (0.66) and 10 days (0.63). The convenience of the model proposed has been supported through these results and the values of probability distribution function. The model proposed improves the previous knowledge about the influence of meteorological factors on grass pollen trend in Badajoz. Despite of goodness adjustment of the results to the obtained model, further long term analysis are needed regarding to other Mediterranean cities for expanding the knowledge of the trends and comparing the forecast in the Mediterranean region.

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